RESTORAL PRINCIPLES IN A WIDEBAND DISTRIBUTED NETWORK

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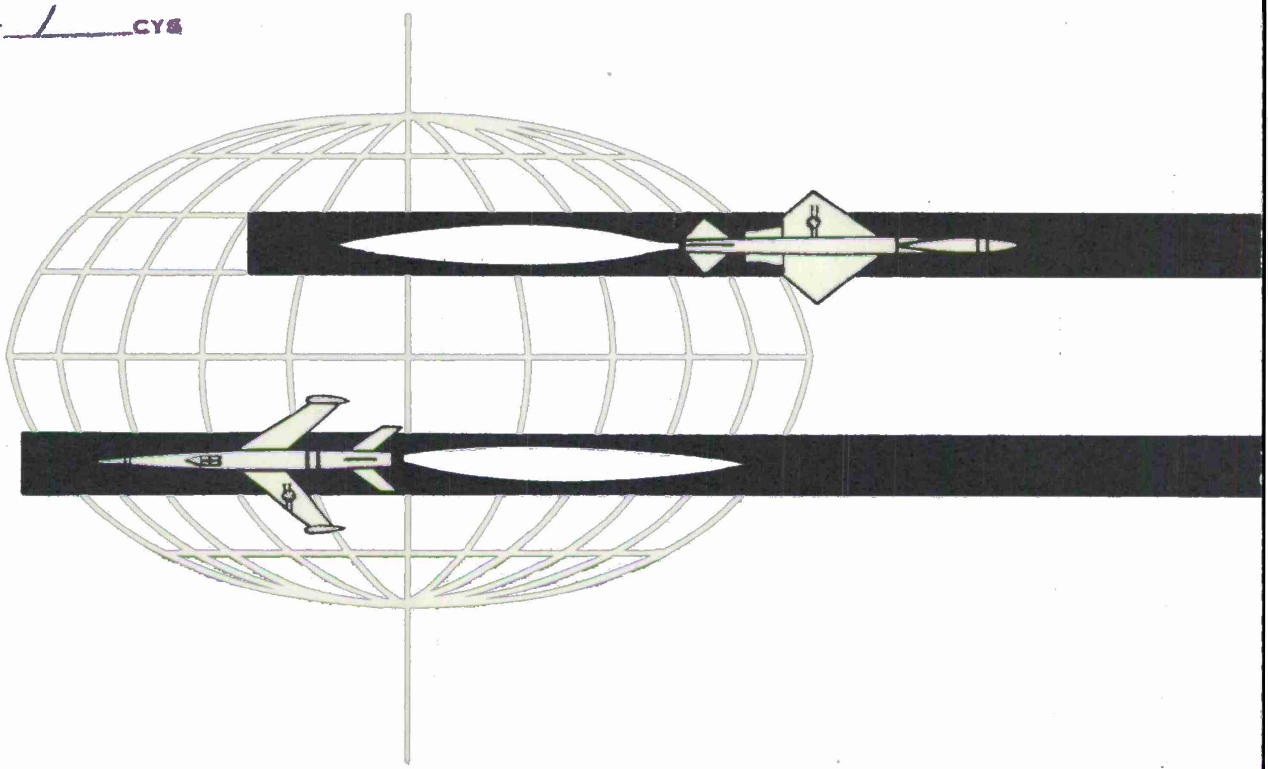

ITT COMMUNICATION SYSTEMS, INC.
PARAMUS, N.J.

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IN A
WIDEBAND DISTRIBUTED NETWORK

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AEROSPACECOM
Deputy for Communication Systems
424 Trapelo Road
Waltham, 54, Massachusetts

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ITT COMMUNICATION SYSTEMS, INC.
Paramus, New Jersey

FINAL REPORT

RESTORAL PRINCIPLES IN A WIDEBAND DISTRIBUTED NETWORK

1.0 GENERAL

Communication failures in the past few years have focused attention on automatic restoral as a means of increasing the reliability and survivability of military communications. These failures have resulted from sabotage of microwave radio relay stations, building collapse, and hurricanes. Each has affected only a single communication point. The use of present manual methods for restoral of service has resulted in normal delay in the order of 30 minutes with complete restoration taking several hours. Under conditions of general war with its much greater loss of facilities, outages far longer than this could be expected. On the basis of studies examining restoral of connections for various bandwidths, the 4 kc channel and the 48 kc group appear to be the most promising units upon which to base a practical system.

One approach to restoral may be found in the multitude of full period allocated circuits that exist at the present time. Many of these circuits are of such importance that additional parallel redundant circuits are provided to assure communication with the required reliability. Often, redundant circuits are provided on a one-for-one or even two-for-one basis, thus increasing costs when the circuits are leased or reducing the traffic-carrying capacity of military owned systems.

A practical restoral system could eliminate the need for redundant circuits, thereby reducing the cost of leased communications or increasing the traffic-carrying capacity of military owned systems, without any reduction in the assurance of the ability to communicate when required.

2.0 RESTORAL OF 4 KC CHANNELS

Restoring 4 kc allocated circuits usually involves one or more "Engineered Military Circuits" (EMC) or "on-call" backup circuits. These may be built up on a manual patched basis or preempted automatically from layouts normally serving other users. In either case, each backup circuit is custom engineered and each provides only one additional 4 kc channel. Special equipment is generally required for preemption and often a single circuit is subject to several levels of preemption, thus further increasing the equipment complexity and limiting the flexibility.

One promising 4 kc channel restoral system would route all allocated 4 kc channels, regardless of the type of traffic carried, via a 4 kc general purpose switching network. Within the network, the allocated channel, once established, would remain permanently connected as long as circuit continuity was maintained. Since normal switching network functions do not continuously monitor the status of the user access links at the extremes of the connection or the inter-switching center connections (trunks) for such a connection, additional special purpose signaling apparatus would be provided at the user terminals and/or switching centers to perform this continuity monitoring function. Once a loss of continuity was noted, however, switching center memory functions would immediately attempt to reestablish the connection through the general purpose network. If the allocated line was of sufficient importance, priority and preemption features of the 4 kc general purpose switched network would be used during reestablishment of a connection to insure completion, at the expense of lower priority traffic if necessary. The 4 kc general purpose switched network would also employ automatic alternative routing, line load control, and other traffic control features to provide maximum service to high priority users.

The 4 kc channel restoral system described above presupposes the existence of a 4 kc general purpose switching network and, further, that the trunks of such a network would be relatively immune to the kind of failure that affects the reliability of present allocated circuits. The first of these assumptions may be realistic; the second is probably not.

3.0 RESTORAL OF 48 KC GROUPS

Restoral of 48 kc groups (twelve 4 kc channels) provides a reasonably stable, general purpose, switched network configuration and capacity, in addition to improving allocated circuit reliability. General purpose switched networks must have this type of stability for efficient use of traffic control features such as priority, preemption, alternative alternate routing, etc.

Investigation of the practicality of 48 kc restoral systems has fallen into the following categories:

48 kc Group Availability
48 kc Group Accessibility
Transmission
Monitoring and Signaling

Switching Hardware
Switching Philosophy

The current status of each of these is described below.

3.1 48 KC GROUP AVAILABILITY

War gaming has shown that only a small portion of the total common carrier transmission facilities within CONUS would be destroyed during an enemy attack. However, the damage pattern is such that much of what remained would be effectively isolated because of the lack of flexible connecting facilities. The 48 kc restoral system is based on making all telecommunications resources available to restore high priority services, preempting commercial traffic if necessary. This system would necessitate bringing all 48 kc groups through restoral nodes where flexible interconnection would be possible.

3.2 48 KC GROUP ACCESSIBILITY

Not all of the facility nodes that appear to be logical candidates for 48 kc group restoral centers are equipped with 48 kc group deriving equipment. Implementation of a restoral system would require this equipment although the total amount of equipment needed is not yet known and cannot be estimated accurately until network design has progressed through survivability analysis and firm restoral node locations have been selected. The network design process is one of postulating a network and then testing the survivability with a computer simulation, making changes, retesting, etc, until the point of diminishing returns is reached.

3.3 TRANSMISSION

The provision of additional restoral points where channels appear as 48 kc groups makes it necessary to determine whether the desired transmission quality of the 48 kc group channel can be maintained. It appears that this will not be a serious problem although some equalization of the frequency attenuation and delay distortion characteristics of the 48 kc channels may be required. Verification of the feasibility of group restoral from a transmission standpoint must also await a more complete network design as well as the development and simulation of the switching philosophy discussed below.

3.4 MONITORING AND SIGNALING

Investigations of monitoring have been primarily concerned with the incompatibilities of the pilot frequencies in use in various parts of the world. Interest has also been evident regarding the relative merits of

link-by-link versus end-to-end monitoring. No serious problems are anticipated in this area although additional equipment must be provided where non-compatible systems interface. Within CONUS, no compatibility problems are expected.

Signaling between restoral nodes is required to permit cooperative and unambiguous reestablishment of 48 kc connections. The most feasible method would be to incorporate the signaling within the 48 kc bandwidth of the restoring channel.

3.5 SWITCHING HARDWARE

Functional specifications for restoral node hardware required for flexible, automatic interconnection of 48 kc channels have been developed by ITT Federal Laboratories under ICS Task SN 1022-0450.

These specifications, published as ESD TDR-63-33, describe the switching matrix and associated controls for a 48 kc restoral system, applicable within CONUS, Alaska, and Canada. The engineering assumptions used as the basis for defining the necessary functions were representative of the communication plant in this geographical area. However, the functional specifications are comprehensive enough to form the basis of a practical automatic restoral system in other areas with only minor modification.

Development of detailed functional specifications for equipment at a restoral node was undertaken to show the practicality from the hardware viewpoint of an automatic restoral system. The system described is not the only one possible, nor is it necessarily the best possible. The detailed functional requirements for a restoral node can be finally selected only after considering tradeoffs involving various degrees of complexity and expense and the possible increase in survivability and reliability. Evaluation of the tradeoffs must again await more detailed network engineering and survivability analysis.

3.6 SWITCHING PHILOSOPHY

The switching philosophy, i.e., the routing and control strategy, is the most crucial item in determining both the practicality and the value of any 48 kc automatic restoral system. The problem here is to determine the optimum path through a network. This problem has been and continues to be intensively investigated by many agencies interested in maximizing some property of the network. The optimum path in a 48 kc restoral system is that path which tends to maximize the traffic capacity of the entire network when the sources and sinks are also considered.

Routing strategies at a node can be divided into two types - strategies requiring status information about only those links impinging on the node, and strategies that require knowledge of the status of all network links. (In detailed design, it may be determined that a node does not necessarily need status information on every network link to perform its routing functions without substantial degradation.)

Where the node knows only the status of the impinging links (typically 3 to 6 for a 48 kc restoral system), the number of possible decisions to be made is small and the equipment needed to perform the decision-making function is simple and inexpensive. The decisions may be random, may be based on preferences stored in a directory memory, may be based on an adaptive scheme, or may combine these techniques in any manner.

Three routing strategies proposed for use at nodes with limited link status knowledge are broadcast routing, trace routing, and maze searching.

Broadcast routing is based upon a decision to route a message to all links simultaneously and to repeat this process at each node throughout the network until the destination is reached. The first path connecting origin and destination is held and all other paths are then released. While the connection is being established, this process ties up many circuits that are not required for the final connection. An additional drawback is that only one call can be established at a time. Broadcast routing can be modified to reduce network saturation during the setup time but no satisfactory method has been found to establish two or more connections simultaneously.

Trace routing is the inverse to broadcast routing in that the path through the network proceeds from destination to origin with the destination node requesting any traffic for completion to itself. Trace routing suffers from the same drawbacks as broadcast routing.

Maze searching involves link-by-link progression through the network with random decisions at each node except for avoidance of closed loops or ring-around-the-rosy.

None of these strategies provides an optimum path in the sense that network capacity is maximized. Broadcast and trace routing do tend to minimize path length to the extent that propagation time through the network is proportional to distance. Directory schemes and adaptive

techniques can be combined with each of the three strategies. Note that maze searching combined with a directory scheme (also known as "pointing labels") is essentially identical to the Bell System routing strategy, i.e., register-to-register working with each switch consulting its directory for the next route.

Where node decisions are based on the status of all network links, the path through the network (and the total network connectivity) can be made optimum in any desired sense. Directory information can be computed in real time or can be precomputed for all electrically possible sub-networks (subsets of links and nodes). This strategy is essentially a directory process.

Real time computation is unusable today because of the multiplicity of nodes, links, sources, and sinks involved, and the inadequacy to present analytic design tools. Further, real time computation is not necessary since once the directory information for a particular network configuration is obtained, it can readily be stored for later consultation.

Precomputation of directory information for networks of the general dimensions of the proposed 48 kc restoral system is expected to be a lengthy and expensive operation. However, detailed design may show that little survivability or reliability is sacrificed by using simplifying approximations that reduce the number of configurations and thus reduce the required directory capacity at each node.

Once an initial computation has been completed, minor additions or subtractions can probably be incorporated without requiring recomputation of all directory information. Again, these tradeoffs cannot be evaluated without a survivability analysis employing a computer simulation of the proposed network with the proposed strategies.

Two basic control configurations can be applied to networks employing routing decisions based on complete network knowledge. In the first, the control is centralized to minimize the requirements for directory memory or data processing equipment. With centralized control, it is not necessary for each node to be aware of link status for the entire network but this information must be provided to the central directory. Since the status information must be accurate and current, considerable path redundancy must be provided for the status channels; thus a great deal of status

information is likely to be available at a particular node in any case. In addition, the node must query the central directory for the proper route each time a connection is desired and these query channels must be reliable and have considerable redundancy.

The second control configuration places a data processor or directory at each node. Status channels between nodes are still required but the need for query channels is eliminated. The use of expensive computers at each node with each computer doing identical computation with identical programs on identical data bases and producing identical directory information is prohibitively expensive. On the other hand, the cost of a directory memory at each node with sufficient capacity to store the routes for all destinations with any possible network configuration is formidable but not overwhelming.

4.0 RECOMMENDED RESTORAL SYSTEM

The 48 kc automatic group restoral system recommended for use with CONUS, Alaska, and Canada is based on the use of a directory at each node with each node having full knowledge of the status of each network link. The directory information would be precomputed for all possible network connectivities enabling the status memory to determine the route to be used. This particular configuration is recommended because it permits maximum use of all the telecommunication resources included with the restoral system.

A node attempting to restore a connection would take charge of tracing the required path through the network, node by node, knowing in advance that no blockage would be encountered. This is a form of originating register control and is desirable (at least initially) to prevent the ambiguities in route selection that might occur due to the propagation time ot status information in the network. Ultimately, it might be possible to reduce the directory route capacity at each node to include only the next node in the path to the desired destination with a particular network configuration.

This restoral system, as embodied in "Functional Specifications for Group Restoral Switching in a Wideband Distributed Network*", encompasses transmission and switching subsystems and a control scheme.

The transmission subsystem provides links capable of satisfying specified traffic and quality requirements for both allocated circuits and trunks

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*ESD TDR 63-331

of the 4 kc general purpose switching network. A nominal 4 kc multi-point broadcast data circuit operating at 600 bps duplex will be maintained between all nodes, to pass network status messages, activate automatic alarm and circuit restoral equipments as necessary, and provide information on system status to display units for human decision makers.

The switching subsystem will receive network status messages, match them against the preprogrammed memory to determine group connection rearrangements required, and operate the actual switching mechanism.

The control scheme must include features to permit day-to-day traffic management of military communications by rearrangement of 48 kc groups leased by the military. However, the control must also insure that commercial groups will not be preempted except in times of actual emergency. During such an emergency, control of the routing strategy should revert to each node with its precomputed directory information.

Planning for a 48 kc group restored system has now progressed to the point where a quantitative measure of improvement of reliability and survivability can be obtained within the next several months. The complexity and quantity of telecommunication facilities involved make it necessary to use computer simulation techniques to obtain these quantitative measures. Results of preliminary studies indicate that continuation of the planning effort is well justified.